

A century after 1906 earthquake, geophysicists revisit 'Big One' and come up with new model

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Almost a century after the 1906 earthquake, Stanford geophysicists have revisited San Francisco's "Big One" and now paint a new picture of a fault that was ready to go and that ruptured farther and faster than previously supposed.

"Our understanding of seismic hazard in Northern California, including the Bay Area, relies on a thorough understanding of this earthquake and the San Andreas Fault," said Professor Gregory C. Beroza, who with graduate student Seok Goo Song and Professor Paul Segall will present their new model of the dynamics of the '06 quake Dec. 5 in San Francisco at the annual meeting of the American Geophysical Union. The meeting is expected to draw more than 11,000 Earth and space scientists from around the world. "Our knowledge of that has a strong influence on estimates of the likelihood of and likely timing of future earthquakes."

Beroza said the 1906 earthquake was a "watershed event" because it convinced geologists that the fundamental theory of how earthquakes work was in fact correct. "That fundamental theory is the elastic rebound hypothesis," he said. "It says that before an earthquake you get the Earth's crust straining and that suddenly the strain is released during an earthquake. Prior to that people had hypothesized about elastic rebound, but for this earthquake there were measurements that showed that said, yes, this was completely consistent with that idea."

In their talk, "Evidence for Supershear Rupture During the 1906 San Francisco Earthquake," Song, Beroza and Segall will explore how slip along the fault evolved during the earthquake. Their work was funded by the U.S. Geological Survey (USGS) and Stanford University.

Why revisit this topic 100 years after the infamous quake?

"The motivation for doing this was there was a large discrepancy between two different models for this earthquake," explained Beroza, who is on sabbatical this quarter at the USGS in Menlo Park, Calif.

One is the seismic model, developed in 1993 by David Wald, then at the California Institute of Technology, and colleagues. The other is the geodetic model, developed in 1997 by Wayne Thatcher of the USGS in Menlo Park. Both Wald and Thatcher have helped the Stanford researchers with data analysis for the current study. The models disagree "in a substantial way," Beroza said.

A tale of two models

For part of his doctorate, Song examined slip on the San Andreas Fault during the '06 quake and how it spread out from the epicenter. Segall, who pioneered a way to use nonrepeated angles to get more out of archival data from the National Geodetic Survey, gave crucial advice necessary to refine the geodetic slip model. Beroza in turn aided the seismic analysis.

The geodetic model requires the measurement of angles on the Earth's surface before and after an earthquake. From mountaintops, scientists employ precise surveying and triangulation to record measurements of the angles between brass discs embedded in "geodetic monuments." Big earthquakes change those angles, and the changes let scientists calculate how much the fault moved. Measurements can be made years after

seismic waves have decayed away.

Researchers using the seismic model employ a completely different type of data: seismic waves-vibrations produced by earthquakes-typically recorded on the other side of the Earth. For the 1906 earthquake, the closest recordings used in this study were from Puerto Rico. Data also came from Europe and Japan.

"This was the early days of seismology, so we didn't have a global seismic network like we do now, so the coverage is kind of sparse," Beroza noted.

Huge plates of crust on both sides of the San Andreas Fault move in parallel but opposite directions. The Pacific Plate slides to the northwest and the North American Plate slides to the southeast. On April 18, 1906, at 5:12 a.m., the fault ruptured, probably starting offshore near Daly City, Beroza said.

The magnitude is 7.7 based on seismic waves but 7.9 based on the geodetic measurements. Due to the characteristics of logarithmic scales, that means the geodetic measurements indicate an earthquake that was twice as big as the one indicated by seismic measurements, Beroza said.

The models differ in earthquake length as well as strength. Both models agree the rupture spread south to San Juan Bautista. But how far north it spread differs depending on the model embraced.

"The question is what happens north of Point Arena," Beroza said. Point Arena is where the San Andreas Fault hits the ocean before coming back onshore at Shelter Cove. The geodetic model shows lots of slip-perhaps 150 kilometers (about 100 miles)-north of Point Arena.

"The seismic model does not agree with that," Beroza said. It suggests a

shorter rupture, ending more or less at Point Arena, he said.

Is there any way for both models to be right?

Supershear solution

Song, Segall and Beroza explored the possibility that both models might hold true if the fault rupture proceeded at "supershear" speed, that is, if the rupture propagated at much higher velocity than previously assumed. This scenario would suggest an earthquake of shorter duration, which in fact was observed on faraway seismographs.

Compressional, or P, waves travel through solids and liquids, and when they cross the planet, they propagate like sound: Squeezed pulses alternate with expanded pulses. They are very fast, traveling through the Earth's crust at about 6 kilometers per second (13,420 mph). In contrast, shear, or S, waves do not propagate in liquids, which cannot store the energy needed to sustain side-to-side motions. S waves wobble side-to-side like shaken jelly and travel more slowly-3.5 kilometers per second (7,829 mph). Seismometers, motion sensors that detect earthquake waves, can distinguish P waves from S waves.

"Supershear is when the slipping part of the fault moves faster than the shear-wave velocity," Beroza said. "It's analogous to supersonic. You get a sonic boom."

If the rupture in the '06 earthquake was supershear, and if the rupture in a future earthquake were to be supershear, that means the shaking of the ground that knocks down buildings and poses most earthquake hazards will be fundamentally different than is commonly assumed, Beroza said.

Getting more information out of the geodetic data allowed Song to obtain refinements confirming slip on the fault north of Point Arena.

"That's useful, but it doesn't resolve the discrepancy," Beroza said.

The Stanford researchers next looked to Wald's seismic data, which assumed subshear rupture speeds of 2.7 kilometers per second (6,040 mph). "Under those assumptions, the seismic data support slip up to Point Arena but no farther," Beroza said.

"We used the same sort of seismic modeling that Wald and others used, and asked the question: Could we fit the seismic data?" Beroza recalled. "Basically what we tried to fit was the amplitude and the duration of the signal." They were indeed able to fit the seismic data, and also the geodetic data, if they allowed the rupture to exceed the shear-wave velocity.

Beroza's interest in supershear rupture as an alternate explanation was rekindled with recent observations of three huge supershear earthquakes—the magnitude 7.4 earthquake that devastated Turkey in 1999, the magnitude 8.1 earthquake that rocked Tibet in 2001 and the 7.9 earthquake following rupture of the Denali Fault in Alaska in 2002.

"The three recent big strike-slip [characterized by horizontal motion across the fault] earthquakes all have this characteristic [supershear rupture]," Beroza said. "Now we're thinking this might be typical behavior for large strike-slip earthquakes, so it's reasonable to think it might have occurred in the 1906 earthquake."

Geophysically, what does supershear rupture mean? "It's telling us that the rupture was closer to being ready to go before the earthquake than we would have assumed otherwise," Beroza said. "If it's really close to ready to go, then the P waves, or the waves that arrive before the S waves, can be enough to trigger slip and get it going supershear."

Beroza calls the proposed supershear solution "a viable resolution of the

conflict" and "a new model for the source of the 1906 earthquake." The Stanford model is now being employed in a coordinated effort led by the USGS to use the revised model together with three-dimensional Earth models to generate simulated ground motions. The researchers will be able to better model how the ground shook in 1906.

What next?

Researchers hope to look at different earthquake scenarios next. "Suppose another big earthquake were to happen on the San Andreas," Beroza posited. "It won't look exactly like the 1906 earthquake. It'll be different. The rupture might propagate in the other direction. It might be subshear. It might be a small earthquake. There are all sorts of possibilities. But since we can't tell ahead of time what's going to happen, in a sense we have to take those different scenarios into account."

Geophysicists will explore those scenarios in San Francisco in April at a scientific meeting on the anniversary of the quake. Engineers at that meeting, held jointly by the Seismological Society of America and the Earthquake Engineering Research Institute, will use information on ground motions to assess risks under different conditions. Someday better knowledge of how the ground shakes could influence building codes and insurance risks, Beroza envisioned.

"We're a long way from that," he cautioned, saying in the shorter term the knowledge may inform policymakers. "The more immediate impact might be that municipalities might take a renewed interest in earthquake risk reduction."

Source: Stanford University

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